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RE-INSTRUMENTATION TECHNIQUE OF IRRADIATED LWR FUEL RODS FOR PRESSURE MONITORING DURING IRRADIATION TESTING AT THE HFR PETTEN

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ABSTRACT

The LWR testing facilities at the HFR Petten have been extended for testing of pre-irradiated and re-instrumented LWR fuel rods. This contribution relates to the re-instrumentation technique of pre-irradiated fuel rods with pressure sensors for the following purposes:

- o Investigation of the transient fission gas release mechanism and fuel rod internal pressure behaviour during transient testing and steady state power operation, and
- o failure detection on fuel rods during transient tests or in LOCA tests.

The re-instrumentation heads with pressure sensors and a gas filling tap are remotely welded to the fuel rods in the hot cells. The welding is then checked for integrity and leaks. Subsequent connection between the fuel rod plenum and pressure monitoring system is performed by an integrated drill in the re-instrumentation head. After transportation to the HFR, the re-instrumented fuel rod is remotely loaded into the standard LWR fuel rod testing facilities. Following completion of the irradiation testing at HFR, the fuel rod is returned to the hot cells for further examinations.

The contribution will address:

- o the hot cell assembly device and re-instrumentation heads,
- o the re-instrumentation technique and experience, and
- o highlight examples of applications.

1. INTRODUCTION

For irradiation testing of single, highly instrumented Light Water Reactor (LWR) fuel rods on the Pool Side Facility (PSF) of the High Flux Reactor (HFR) Petten, special devices for use in the Boiling Water Fuel irradiation Capsule facilities (BWFC) were developed. These special irradiation capsules enable pressure and central temperature of the fuel to be monitored during irradiation and have been successfully operated at HFR since 1977 in a series of longterm tests.

Based upon the experience gathered from these and other LWR test programmes performed since 1976 at HFR using the BWFC installation, follow-up tests are being designed where pressure measurement of pre-irradiated LWR fuel rods from nuclear power plant is required during subsequent irradiation testing at the HFR. The new design will enable the continuous monitoring of fuel rod pressure, advent of fission gas release during power transient tests and early warning of fuel rod cladding failure.

Whereas the previous tests using instrumented fuel rods have all been conducted with previously unirradiated standard fuel rods, the new device described in this report will enable pressure monitoring equipment to be connected to pre-irradiated fuel rods before they are installed for tests at the HFR. The design enables both Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) type fuel rods to be re-instrumented remotely in the hot cells operated by the Netherlands Energy Research Foundation (ECN), at their Laboratory for Strongly radioactive Objects (LSO) in Petten. Delivery to the HFR can then be made in the normal way as for other pre-irradiated rods, via the transfer cell at HFR before eventual loading into the reloadable irradiation devices belonging to the BWFC in-pool facilities.

The following report describes the design of the two types of re-instrumented fuel rod and the various stages and method of assembly.

2. THE RE-INSTRUMENTED FUEL ROD DESIGNS

Drawings of the two different versions of the re-instrumented heads and fuel rods are shown :

- o Fig.1. : For PWR fuel rods.
- o Fig.2. : For BWR fuel rods.

The two designs differ mainly with regard to the methods of sealing the integral drill shaft and in doing so, accommodate the differences between the type of end fittings on PWR or BWR fuel rods.

It is possible to load both types into the appropriate PWR or BWR re-loadable irradiation capsules belonging to the BWFC, PSF facilities at the HFR (See Fig.3.).

The lower end of the instrumented head is fitted with a stainless steel to Zircaloy transition sleeve which is welded to the top end of the fuel rod. The fuel rod is then penetrated by an integral drill contained within the head, thereby connecting the fuel rod to the gas pressure measuring line and the pressure transducers. The drill is sealed during the hot cell operations, (which includes drill penetration of the fuel rod), by a neoprene quad 'O'-ring seal after which it is superseded by two metal seals. One seal (ball and cone type) situated below the neoprene seal and a second seal (Dilo type) above the neoprene seal. The entire instrumented head and pressure monitoring system is contained within an outer secondary containment, comprising a cylindrical box with a metal 'Dilo' seal cap and a metal hose leading to a connection box for the attachment of external gas and electrical instrumentation.

The connection box, as shown in Fig.4 contains the two pressure transducers and an isolation valve leading to and from the primary gas line connected to the fuel rod. This valve and external connection is used in the gas filling stages during the hot cell operations. After use, the valve is closed and leak tested. The upper side of the connection box supports the electrical connector serving the pressure transducers. A built-in valve in the plate forming the top of the box, can be remotely operated to enable connection of the secondary gas circuit in the lower containment to the PVC hose protecting the extension cable, Fig.5. By this means, release of contaminated air trapped in the lower section during hot cell operations, or fission gas leakage from the primary containment cannot be directly released to the upper section within the PVC extension hose. The lower containment secondary gas circuit can therefore be isolated at any time and the upper connection cap and PVC instrument hose gas circuit swept to the HFR off gas filter system prior to disconnection. The pressure transducers have been selected to withstand the full system pressure within the test capsule and have metal membranes set in mountings which are seal welded into their respective holders in the primary measuring circuit.

Fig.4 and 5 show in detail the upper end of the connection box, the extension cables, the stem for remote operation of the secondary containment isolation valve, a reference thermocouple, the PVC hose for protection of the cables and the two gas connections for sweeping and pressurization of the extension system and secondary containment. The upper end of the extension system is fitted with leak tight connectors for coupling the system to the out of pile gas and electrical instrumentation.

A 'Dilo' type metal seal encircles the top end of the fuel rod and forms a seal within the irradiation capsule when screwed down into position using the large nut assembled above. The outer circumference of the nut is in the form of a gear wheel and enables remote turning for loading or unloading the fuel rod from its capsule whilst immersed in the HFR pool.

With the capsule loaded into an irradiation support, the metal hose connection to the re-instrumented fuel rod is located within the support and extends upwards to a point where the transducer connection box is secured.

3. HOT CELL FACILITIES AND ASSEMBLY EQUIPMENT

3.1 The Handling Cells

The facilities at the LSO include 4 high activity cells which are mainly used for non-destructive examination (NDE) of fuel rods and irradiation rig dismantling for sample recovery, (see Fig.6.), It is in one of these cells that the re-instrumentation of the LWR fuel rods is conducted.

For investigations of irradiated LWR fuel rods, the hot cells are equipped with special devices for:

- o Assembly of pre-irradiated fuel rods with support and centring pieces (including argon-arc welding capabilities).
- o Dismantling of irradiated fuel rods and irradiation rigs.
- o Visual inspection, including video recording (colour).
- o Gamma scanning on single and multiple isotopes and Kr-85 measurement in the plenum region for non-destructive determination of fission gas release.
- o Eddy current check of cladding integrity.
- o Profilometry (diameter measurement).
- o Length measurement.
- o X-ray radiography of components.
- o Remote welding attachment of fuel rod pressure measuring system to pre-irradiated fuel rods (See Fig.7).

3.2 Fuel rod transfer and transportation

At the rear of the handling cells is an interconnected handling bay (Fig.8.) where access is provided for road vehicles to enter for loading or unloading of the transport containers.

Shielded transport flasks are available on the Petten site for transporting the fuel rods between the LSO and the HFR. The re-instrumented fuel rods are first loaded into a standard transfer vessel as shown in Fig.9, before being loaded into a shielded container for transportation.

For external transportation of the pre-irradiated fuel rods between the Petten site and the sponsors laboratories, arrangements are made between JRC Petten and the sponsors. Transport is invariably carried out by a special haulage company using their own shielded transport containers and equipment.

3.3 Special assembly jig

Fig.10 shows the special assembly jig which is located within the handling cell for the purpose of accurately positioning the component, parts of the re-instrumentation head and fuel rod during the various stages of remote handling assembly.

Insert bushes for PWR or BWR fuel rods are available and can be interchanged from within the cell when required.

3.4 Welding equipment

The welding equipment used to attach the instrumented head to the fuel rod comprises a welding power supply unit and a specially designed tube welding head. This combination forms an automatic tube welding system which is normally used for the fusion welding of metal tubes, pipes and fittings. The complete power supply and control unit is situated outside the hot cell and the welding head is located within the assembly jig in the hot cell. The adaptor cables and argon gas lines which are connected between the power source and the welding head are passed into the cell via a special removable shield plug which is mounted in the cell wall using gas tight 'O' ring seals.

Inserts are available to change the internal diameter of the welding head such that either PWR or BWR rods and re-instrumented heads may be accommodated within. For welding the Zircaloy components joining the fuel rod to the instrumented head, a 1,6 mm diameter, Tungsten Type WZ-8 electrode with 0,8% Zirconium-oxide, is used.

Development tests have been carried out to determine the correct settings for the two types of weld configurations required for the attachment of the PWR and BWR to their respective instrumented heads. It was found that high quality welds could be regularly reproduced with the equipment.

3.5 Gas filling panel

A special gas filling panel has been designed to enable helium gas filling of the fuel rods and assessment of the extra void volume comprising the internal gas passages within the instrumented head. The panel includes facility for evacuating and purging the instrumented head and back filling with high purity helium prior to drilling through to the fuel rod plenum. A line diagram of the gas panel circuit is shown in Fig.11.

The gas filling circuit contains a variable volume vessel V2 (See Fig.11.), which is used to determine the void volume of the gas circuit within the instrumented heads. The vessel V2 has been fitted with an internal piston which is connected to a threaded shaft and handwheel. By operating the handwheel, linear displacement of the piston can be achieved and hence a change in the volume of V2. A vernier scale is provided to measure the position of the piston, one revolution of the handwheel

displacing the piston 1 mm which is equivalent to 0.1 cm³ change in volume. It is possible to change the volume of the vessel from 0 to 10 cm³. By using the vessel V2 to change the volume of the gas circuit and noting the resulting absolute pressure and temperature changes, it is possible to use perfect gas laws ($P_1 \cdot V_1 / T_1 = P_2 \cdot V_2 / T_2$) to determine the internal internal volumes of the circuit and hence that of the instrumented head attached to the fuel rod.

3.6 Drilling machine

The drilling machine used to penetrate the fuel rod after attachment of the instrumented head comprises a heavy duty hand-operated electric drill with a remote variable speed control unit. The drilling machine is mounted in the assembly jig as shown in Fig.10. The variable speed control unit is contained within the gas control panel outside of the hot cell, supply cables being fed to the drilling machine via the shield plug in the cell wall.

A hexagonal key is assembled in the chuck of the drilling machine. The machine can be positioned over the instrumented head and lowered onto the matching hexagon on the protruding end of the built-in drill shaft. Mechanical loading of the drill is provided merely by hanging a 1.16 kg weight on the end of the drilling machine arm.

The drilling machine is fitted with an indicator to show the drill position and depth. It is also possible to restrict the depth of drilling by using a special mechanical stop and series of graded spacers with which the depth can be pre-determined. This facility is required in order to prevent the ball and cone seating of the drill shaft being damaged by coming into contact during drilling.

Development tests have proven that the ideal drilling speed required to penetrate the fuel rods is around 650 r.p.m. The depth the drill is required to drill is approximately 5 mm for PWR or BWR fuel rods and takes on average around 12 seconds drilling time. Special high speed cobalt (5%) alloyed drills are installed in the instrumented heads and enable a short drilling time to be achieved. This factor was found to be very important during the development tests since long drilling times can cause overheating of the drill shaft 'O' ring seal and eventual gas leakage.

4. MANUFACTURE AND ASSEMBLY

4.1 Specification of key components contained in the assembly

4.1.1 Fuel rods

Both PWR and BWR rods will be re-instrumented and prepared for irradiation tests at HFR. The main characteristics of these fuel rods are summarized below in Table 1 overleaf.

Table 1 MAIN PWR AND BWR FUEL ROD DATA

<u>Type</u>	<u>PWR</u>	<u>BWR</u>
Manufacturer	Siemens UB, KWU	
Fuel	UO ₂ or MOX	UO ₂
Enrichment	3.2% or less	3.2% or less
Fuel rod diameter	10.75 mm	12.5 mm
Fuel rod length	390 mm	390 mm
Length of fuel stack	320 mm	320 mm or less
Cladding material	Zircaloy-4	Zircaloy-2 or 4
Filling pressure (new)	22 bar	1 or 6 bar
Filler gas	Helium	Helium
Pre-irradiation time at power reactor	up to 5 years	up to 5 years

4.1.2 Thermocouples

Reference temperature measurement in the region of the transducer connection box is via a thermocouple fitted within the upper connection cap (See Fig.5).

<u>Manufacturer</u>	<u>Type</u>	<u>Material</u>	<u>Range</u>
Sodern, Suresnes France	Thermocoax 2ABAC10A12 O3/1550cm /TI/X-Ray	Chromel/P-alumel Al ₂ O ₃ insulation, SS sheath	0 - 600° C

4.1.3 Pressure transducers

Pressure measurement in the primary gas line connected to the fuel rod is made via the pressure transducers DBS1 and DBS2 (See Fig.4 and Fig.15). A choice or combination of two of any of the following three types of pressure transducer may be installed:

<u>Manufacturer</u>	<u>Type</u>	<u>Materials</u>	<u>Range</u>
Transamerica CEC	4-313-0001 Diaphragm Differential	AISI 416	0 - 70 bar 110 bar max. 210 bar burst -54 to +120° C
Transamerica CEC	1000-0009 Diaphragm Absolute	AISI 416	0 - 70 bar 110 bar max. 210 bar burst -20 to +110° C
Dynisco GmbH	IDA 370-1C Diaphragm Differential	SS X5Cr CuNi1644 Mt.1.4542	0 - 100 bar 200 bar max. 300 bar burst -40 to +120° C

4.2 Testing during assembly

Tests during assembly include:

- o gas system flow tests,
- o x-ray check of welds (weld of fuel rod to head not included),
- o pressure and leak tests as specified on main drawings,
- o thermocouple loop and insulation resistance checks,
- o transducer bridge and insulation resistance checks,
- o calibration and functional test of pressure transducers,
- o check of all relevant dimensions,
- o check of proper connection and polarity of connectors,
- o check of fit into capsule and carrier,
- o check of cleanliness and
- o visual inspection.

4.3 Final testing prior to attachment of fuel rod in handling cell

These tests include:

- o pressure leak testing,
- o ascertaining size of void volume within gas circuit of helium filling panel,
- o check on insulation resistance and continuity of all electrical components and connections,
- o functional check of pressure transducers,
- o check of main dimensions,
- o check of rig handling features and
- o check of cleanliness.

5. ASSEMBLY IN THE HOT CELL

5.1 Preparation of the Fuel Rod and Instrumented Head

In the handling cell, the following inspection and work is carried out on the fuel rod:

- o The fuel rod is inspected to identify top and bottom of the rod (balance about centre, plenum at lighter end) and to check that the identification number is correct.
- o The centring pieces are assembled to the lower end of the fuel rod and secured by tack welding at two positions 180 degrees opposed.
- o It is then checked that the rod assembly will pass into a calibre representing the inner diameter of the irradiation capsule into which the fuel rod will finally be assembled.

5.2 Assembly Procedure

The following procedure describes the actions to be taken during the assembly within the hot cell during the re-instrumentation of a fuel rod. The procedure is the same for PWR or BWR rods apart from the attachments of the instrumented head at the top of the fuel rod. i.e. sleeved joint for PWR rods and a screwed joint for the BWR rods.

5.2.1 Preparation of Fuel Rod

- o All components are introduced into the handling cell.
- o The top end of the rod is abraded with emery tape to remove oxidation (on BWR rod a weld filler plug is also fitted).

5.2.2 Installation of Assembly into Welding and Drilling Stand

- o The fuel rod is entered into the assembly jig (Fig.10.).
- o The instrumented head is placed into position above the fuel rod and attached at the correct height for welding.

5.2.3 Welding of Fuel Rod to the Head

- o The correct centring clamps are fitted to the welding head.
- o The welding electrode is correctly adjusted.
- o The appropriate settings of the welding equipment are made.
- o The welding head is clamped around the fuel rod.
- o The weld run is completed and visually inspected.
- o A re-run of the weld may be carried out if required.

5.2.4 Pressure Leak Tests and Helium Gas Filling

After the fuel rod has been welded to the head, it will be possible to carry out standing gas leak tests not only to prove the integrity of the weld, but also the primary gas line to the pressure transducers and the isolation valve Item 65 (Fig.11).

- o The system is filled to 15 bar with helium and left on a standing pressure test for 48 hours. No detectable leak is permitted.

5.2.5 Derivation of Void Volumes within the Unit

Using the variable volume vessel V2 shown in Fig.11, it is possible to change the void volume between the top of the fuel rod, the pressure transducers and the gas panel and from the resulting pressure changes, to calculate the volume:

- o The isolation valve IV65 (Fig.11) is closed and the volume varied to enable calculation of void volume in the panel up to the valve.
- o The valve IV65 is opened and the process repeated. The unknown volume in the pressure measuring line can thus be derived.

5.2.6 Final Helium Gas Filling of System

It is now necessary to fill the void volume with high purity helium.

- o Using the vacuum pump (Ref. Fig.11), the system is evacuated and then back filled with helium from the bottled supply.
- o The process is repeated several times until the system contains only pure helium.
- o The helium pressure is raised to the desired fill pressure level (normally 6 bar absolute) and the isolation valve IV65 finally closed for the last time.
- o The helium on the gas panel supply side of IV65 is vented and a standing pressure test conducted over 48 hours to ensure that there is no gas leakage from the instrumented head gas system. (Pressure indication given by transducers DBS1 and DBS2 Ref. Fig.11.)

5.2.7 Drilling Operation to Penetrate Fuel Rod

Having confirmed that the system is gas leak tight, the isolation valve IV65 must under no circumstances be re-opened otherwise gas released from the fuel rod after the completion of the drilling operation will escape along the supply line to the gas supply panel outside of the Handling Cell.

- o The drilling machine can be connected to the assembly and the 1.16 kg weight attached to the arm.
- o The drilling machine is operated at around 650 r.p.m., and stopped when the required drill depth has been reached.
- o Correct drill depth is registered by an indicator on the assembly jig and penetration of the fuel rod by a sudden pressure change indication from the two pressure transducers DBS1 and DBS2.

5.2.8 Final Sealing of Metal Seat on Drill Assembly

- o The drilling machine is now removed and the ball and cone metal seal of the drill shaft closed at a pre-determined torque using a special pre-set torque wrench.
- o The back-up Dilo seal is assembled over the top of the drill shaft and closed with a pre-determined torque.
- o Once all seals are in place, a standing leak test is conducted over 48 hours. No detectable leak is permitted.

5.2.9 Final Assembly and Preparation for Removal from Handling Cell

- o The Dilo Cap for the secondary containment, (Items 1,2,3 & 4 Fig.2.) are assembled over the top end of the assembly and sealed with a pre-determined torque.
- o A special connector from the helium gas supply panel is mounted over the top end of the transducer box and the secondary containment pressurized to 3 bar absolute.
- o A standing pressure test is conducted for a period of 24 hours. Any leak must not cause a pressure drop of more than 0.03 bar/hour.
- o Upon satisfactory completion of the leak test, pressure is released from the secondary containment.
- o The fuel rod may be removed from the assembly jig and assembled into BWFC transport vessel.
- o The entire assembly is then placed in a special vessel as shown in Fig.9 ready for removal from the hot cell and transportation to the HFR in a special shielded container.

6. CONCLUSIONS

Using pre-irradiated re-instrumented fuel rods for testing at the HFR obviates the need to use fresh fuel rods which require long term irradiation at HFR before a desired high burn-up is reached. This becomes a particular advantage where transient and investigative tests are required on high burn-up LWR fuel rods.

It is anticipated that the design of the fuel rod pressure measuring circuit will enable equipment for gas analysis to be connected directly at the transducer secondary containment box. Such an operation can take place at the LSO hot cells after irradiation of the fuel rod at the HFR and will enable the gas contents to be vented for analysis via the stop valve IV65, instead of using the usual and more difficult puncture technique.

The technique described in this paper is still in it's infancy in so much that only one BWR re-instrumented rod has been prepared to date. It is anticipated however that another BWR unit plus six PWR units, presently under construction will be completed by the early part of 1990.

The key aspects of the technique are clearly the welding and drilling operations. In both cases extensive development work has confirmed that these operations can be conducted with repeatable success. It is considered that as more experience is gained with this new technique, further refinements of the tooling, equipment and procedures will ensue.

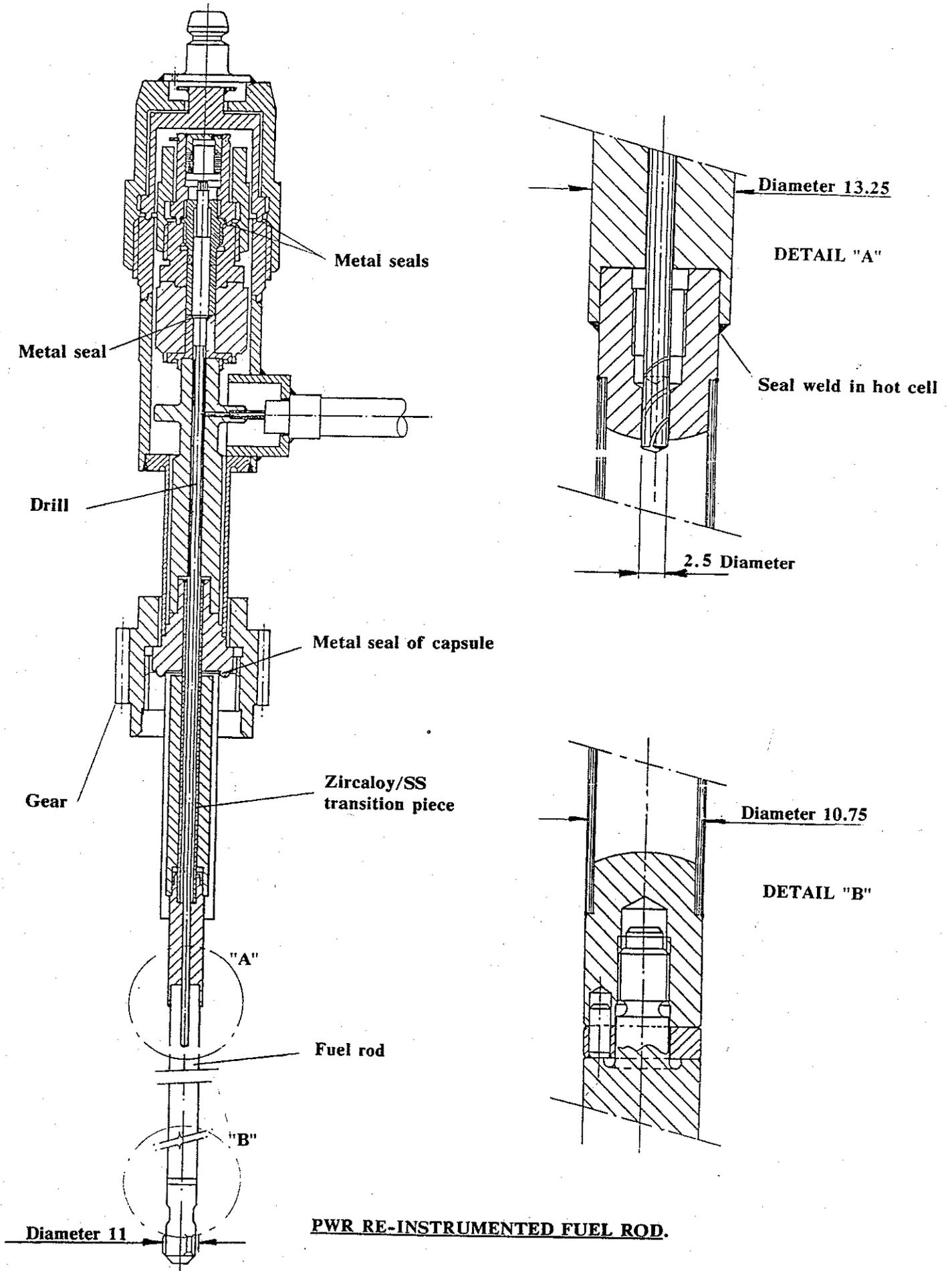
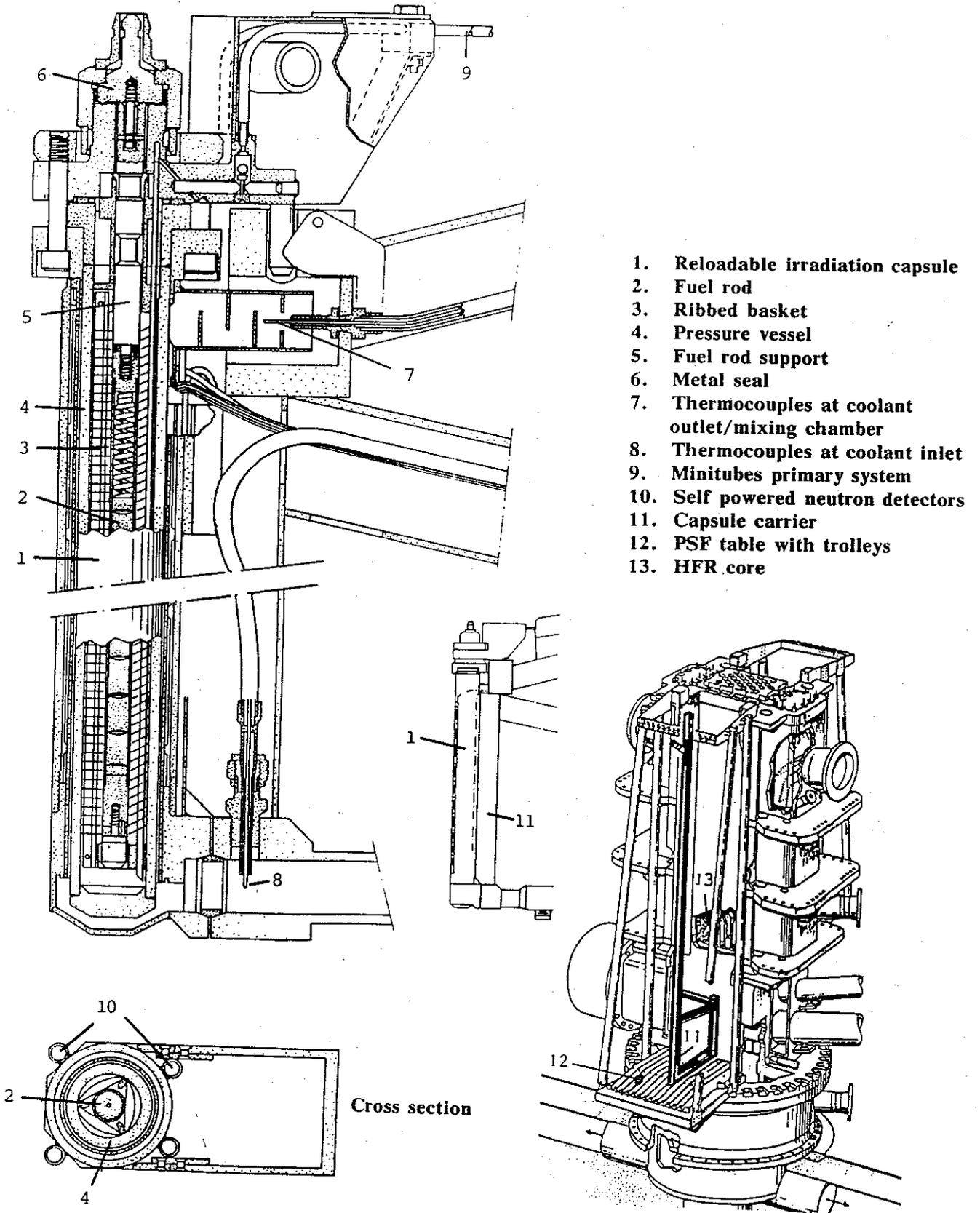


Fig.1.



STANDARD TYPE BWFC IRRADIATION CAPSULE

Fig.3.

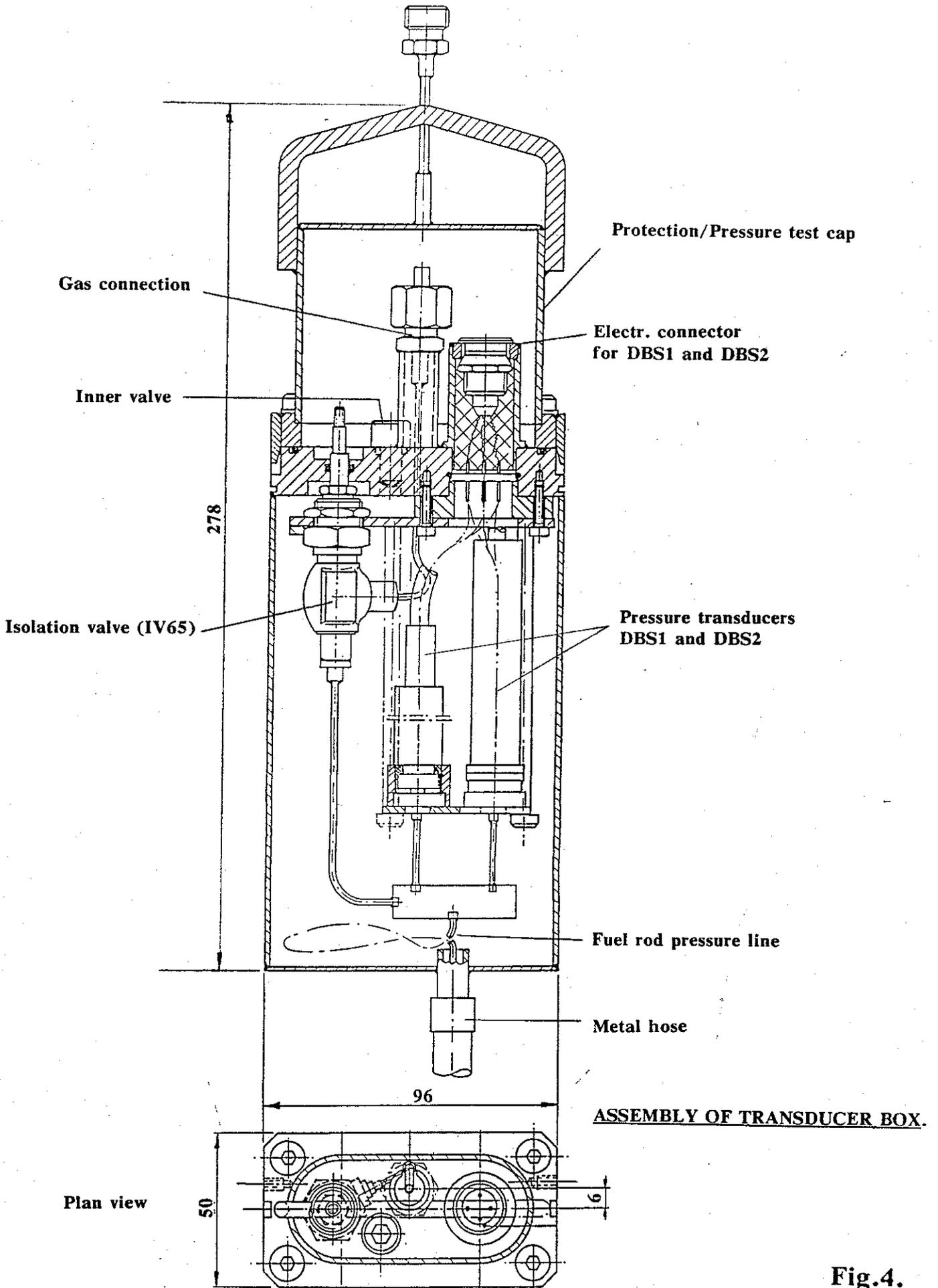


Fig.4.

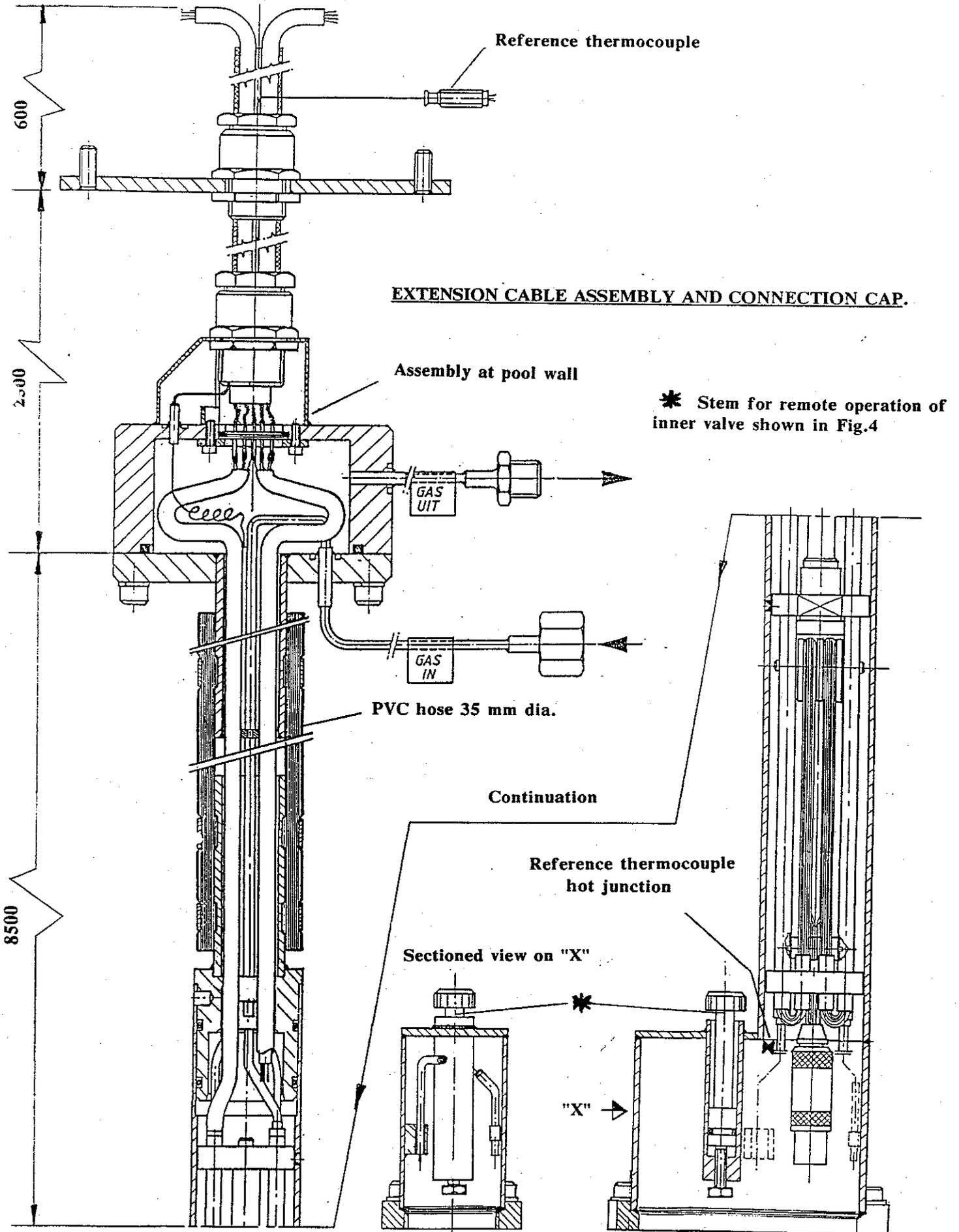
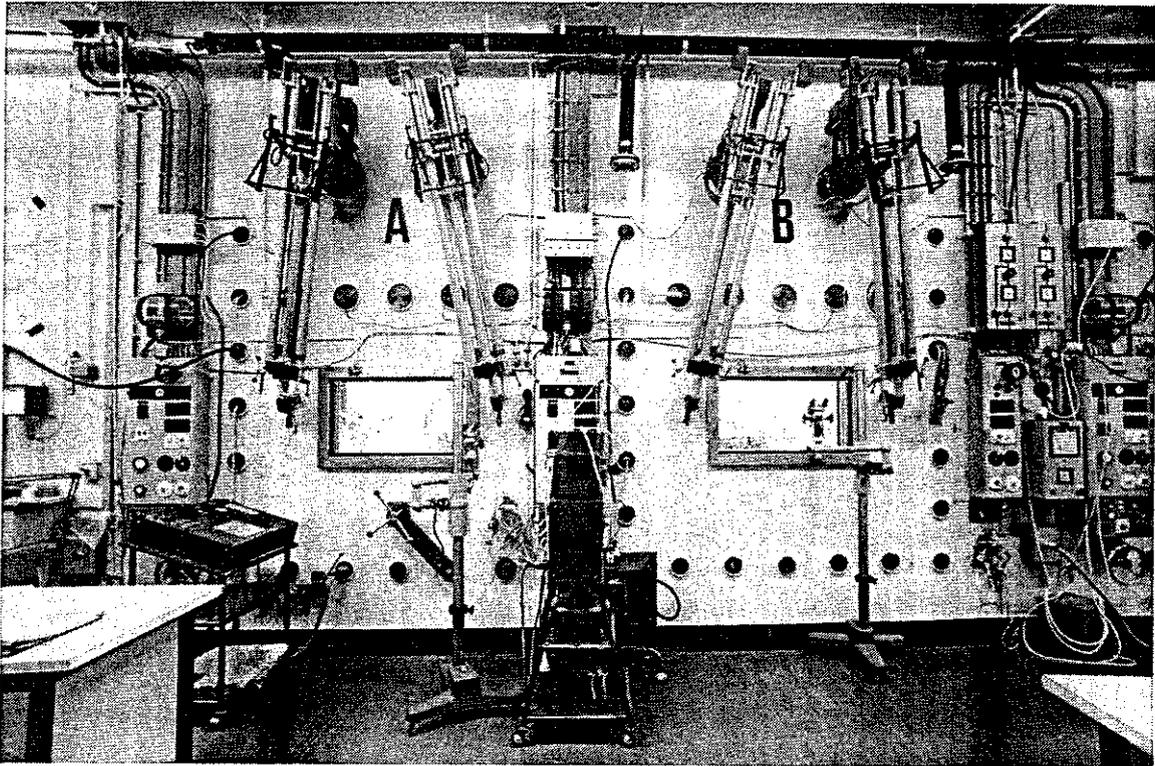
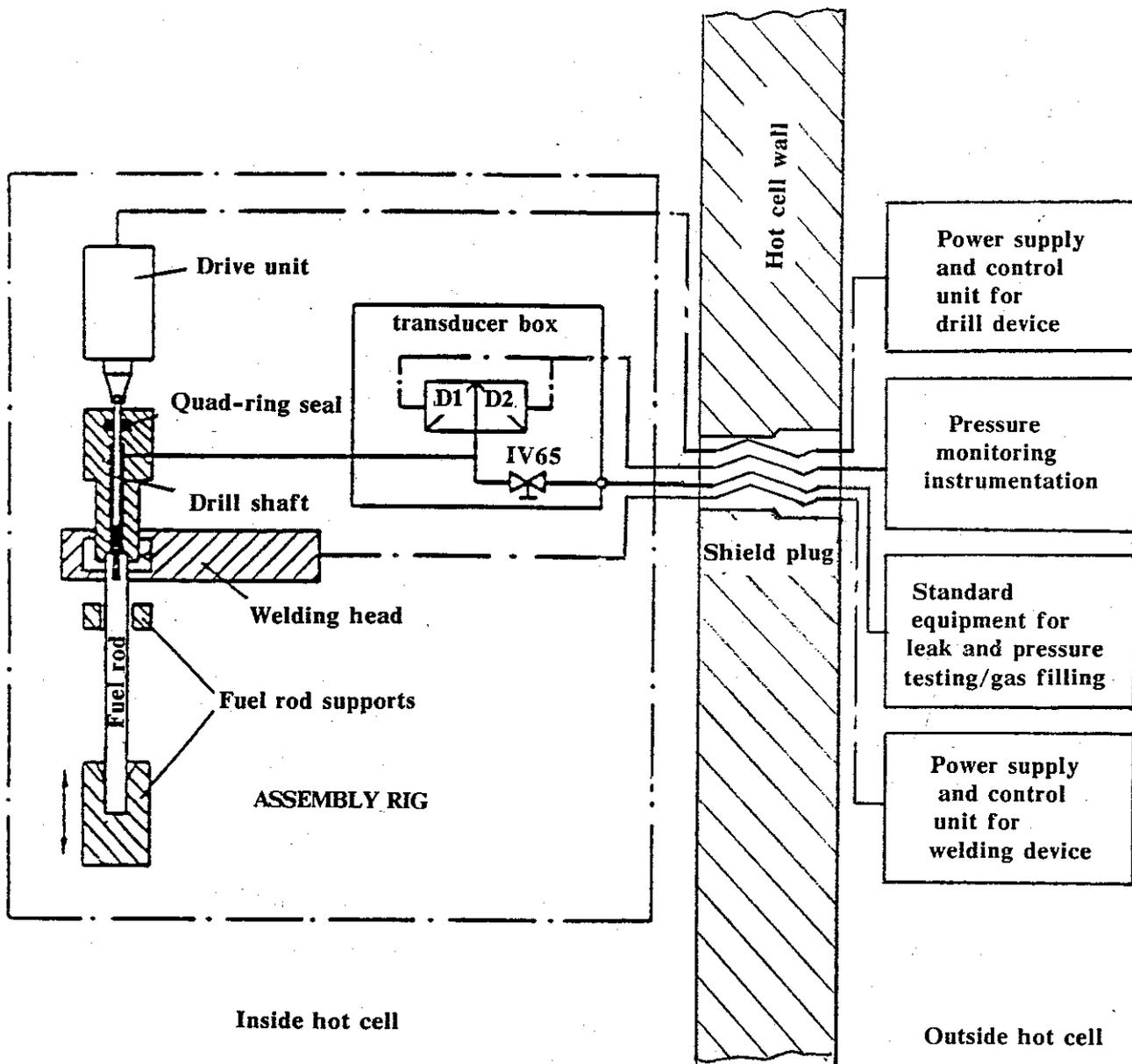


Fig.5.



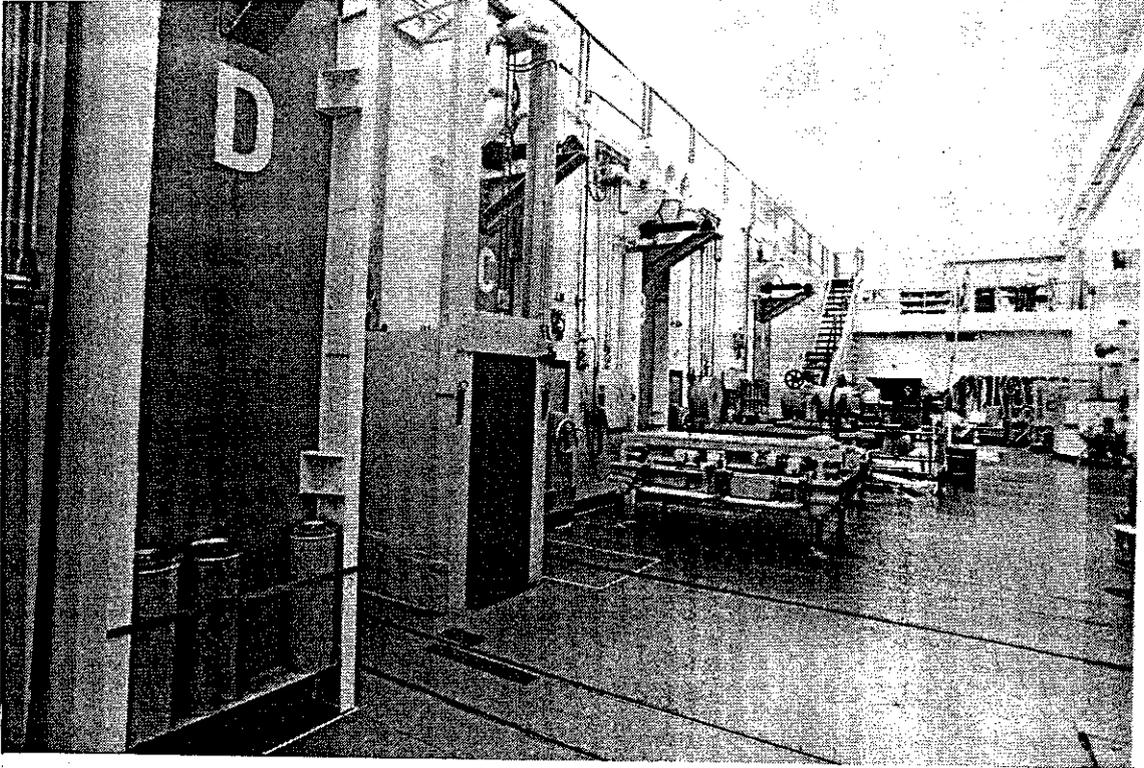
FRONT VIEW OF THE HIGH-ACTIVITY CELLS AT THE L.S.O.

Fig.6.



**BLOCK DIAGRAM OF THE HOT CELL ASSEMBLY RIG FOR THE
RE-INSTRUMENTATION OF LWR FUEL RODS.**

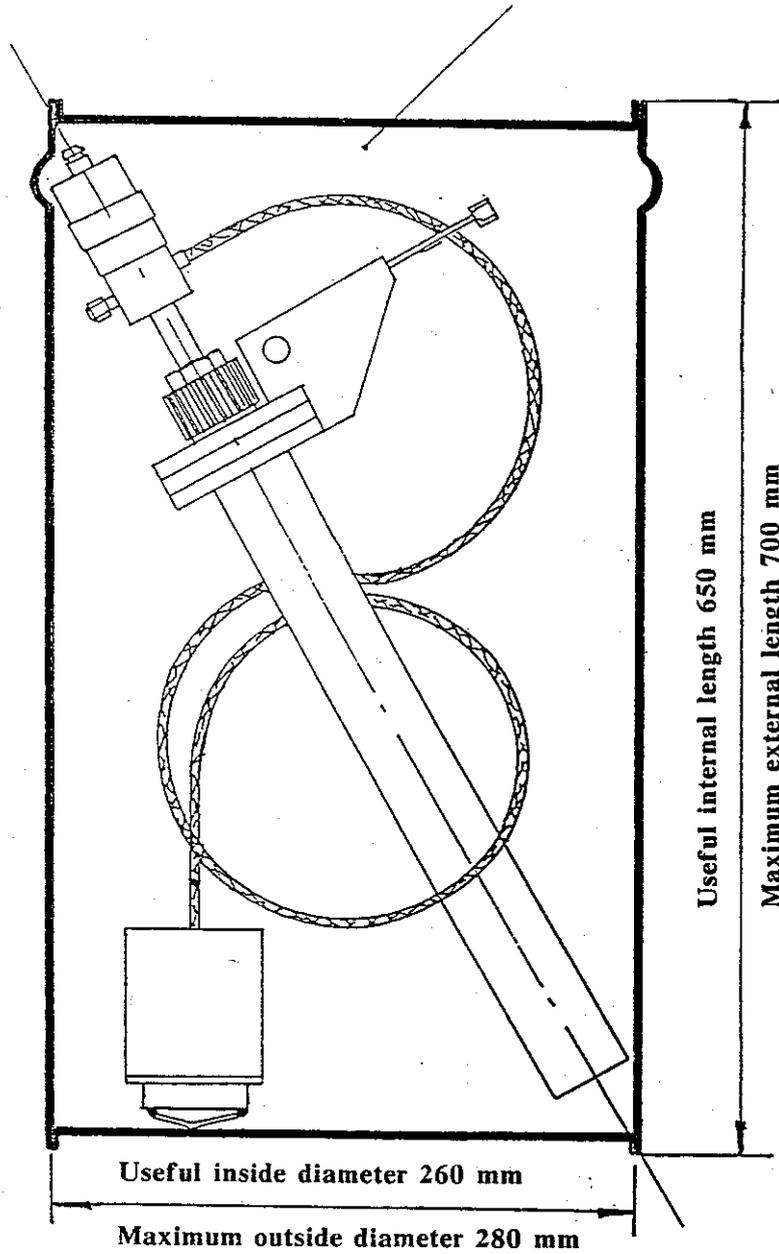
Fig.7.



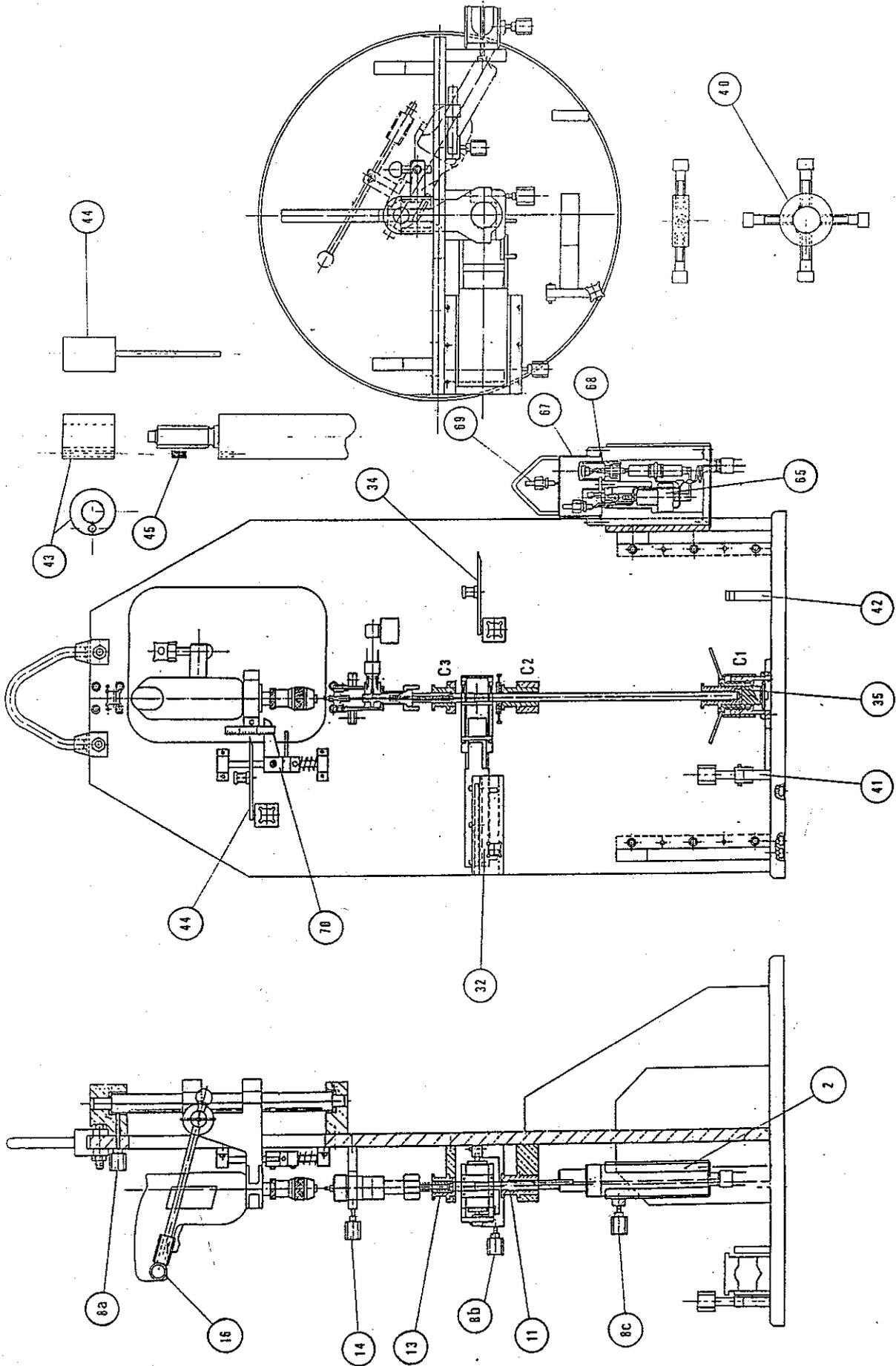
FLASK HANDLING BAY AT THE L.S.O.

Fig.8.

Standard transportation vessel for
radioactive materials

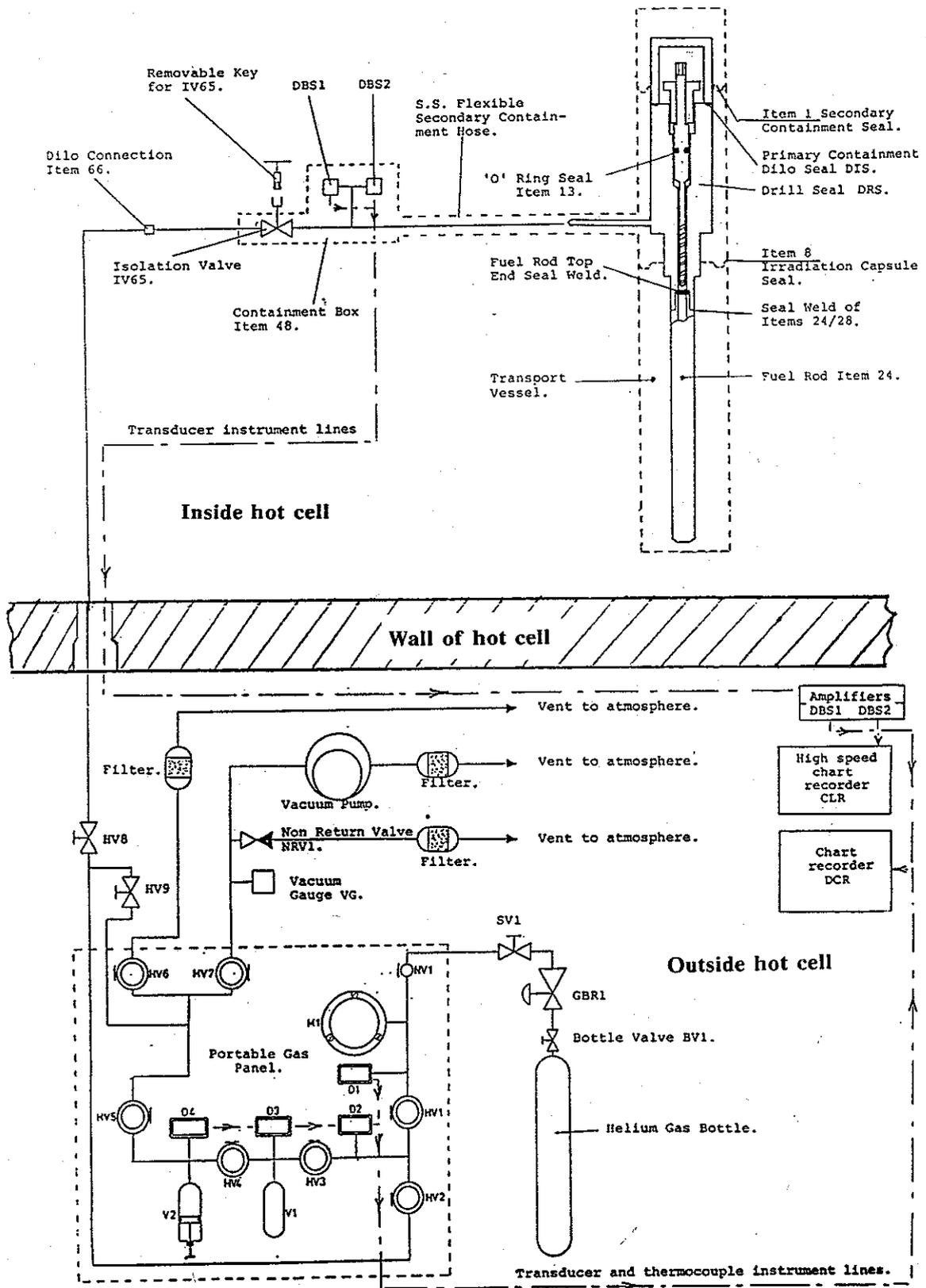


METHOD OF STOWAGE OF RE-INSTRUMENTED LWR FUEL ROD FOR
TRANSPORTATION.



WELDING AND DRILLING JIG.

Fig.10.



HELIUM GAS FILLING CIRCUIT.

Fig.11.